DRAFT
Allen, Wychmere
and Saquatucket Harbor Embayment Systems
Total Maximum Daily Loads
For Total Nitrogen
(Report # 96 TMDL-15   Control #312.0)

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS
MATTHEW A. BEATON, SECRETARY
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
MARTIN SUUBERG, COMMISSIONER
BUREAU OF WATER RESOURCES
DOUGLAS FINE, ASSISTANT COMMISSIONER

April 2015

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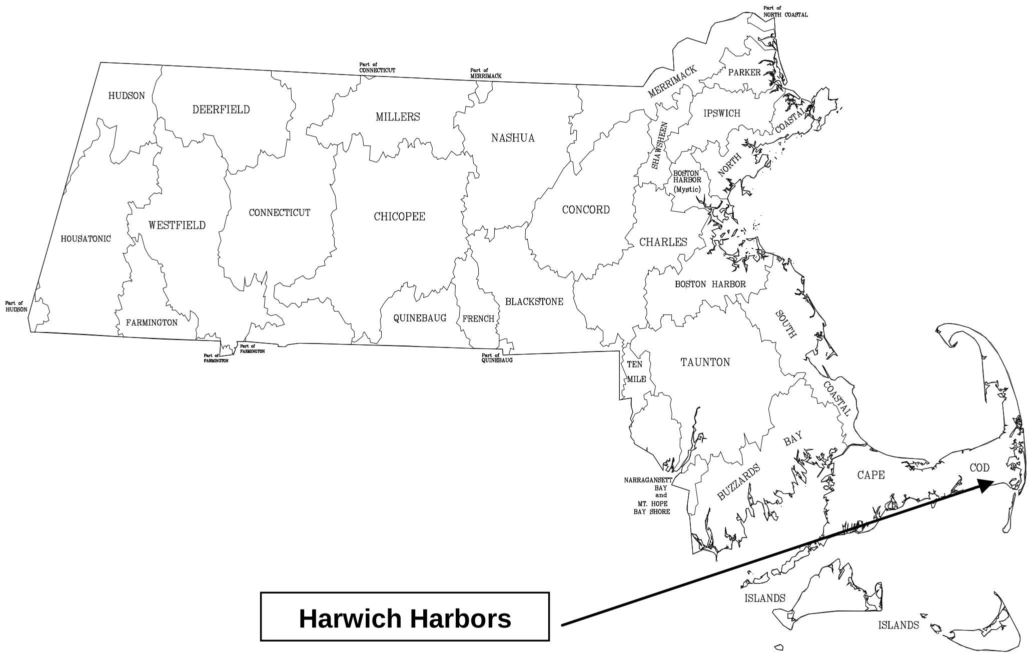


Key Feature: Total Nitrogen TMDLs for Allen, Wychmere and Saquatucket Harbors

Location: EPA Region 1

Land Type: New England Coastal

303d Listing: Saquatucket Harbor (Segment MA96-23_2012) is impaired for pathogens and is listed in category 4a (TMDL completed) of the 2012 MA Integrated List of Waters. Saquatucket, Allen and Wychmere Harbors were found to be impaired for nutrients during the MEP study and will be listed in a future List of Waters as impaired.

Data Sources: University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Town of Harwich

Data Mechanism: Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model

Monitoring Plan: Town of Harwich monitoring program (with technical assistance from SMAST)

Control Measures: Sewering, Stormwater Management, Fertilizer Use Bylaws, Attenuation by Impoundments and Wetlands

Executive Summary

Problem Statement

Excessive nitrogen (N) originating from a range of sources has added to the impairment of the environmental quality of the Allen, Wychmere and Saquatucket Harbor Embayment Systems. Excessive N is indicated by:

- Undesirable increases in macro algae
- Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
- Reductions in the diversity of benthic animal populations
- Periodic algae blooms

With proper management of N inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

Coastal communities rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings could result in an overabundance of macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayments. As a result of these environmental impacts, commercial and recreational uses of Allen, Wychmere and Saquatucket Harbors will be greatly reduced.

Sources of Nitrogen

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
    - Natural background
    - Septic Systems
    - Runoff
    - Fertilizers
    - Wastewater treatment facilities
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

Figures ES-A- ES-C below illustrate specific sources of N and the percent contributions of each. Values are based on Table ES-1 and Table IV-3 from the Massachusetts Estuaries Project (MEP) Technical Report (http://www.oceanscience.net/estuaries/documents.htm). Most of the present controllable load to this system comes from septic systems.

Figure ES-A: Percent Contributions of All Nitrogen Sources to Allen Harbor Embayment System

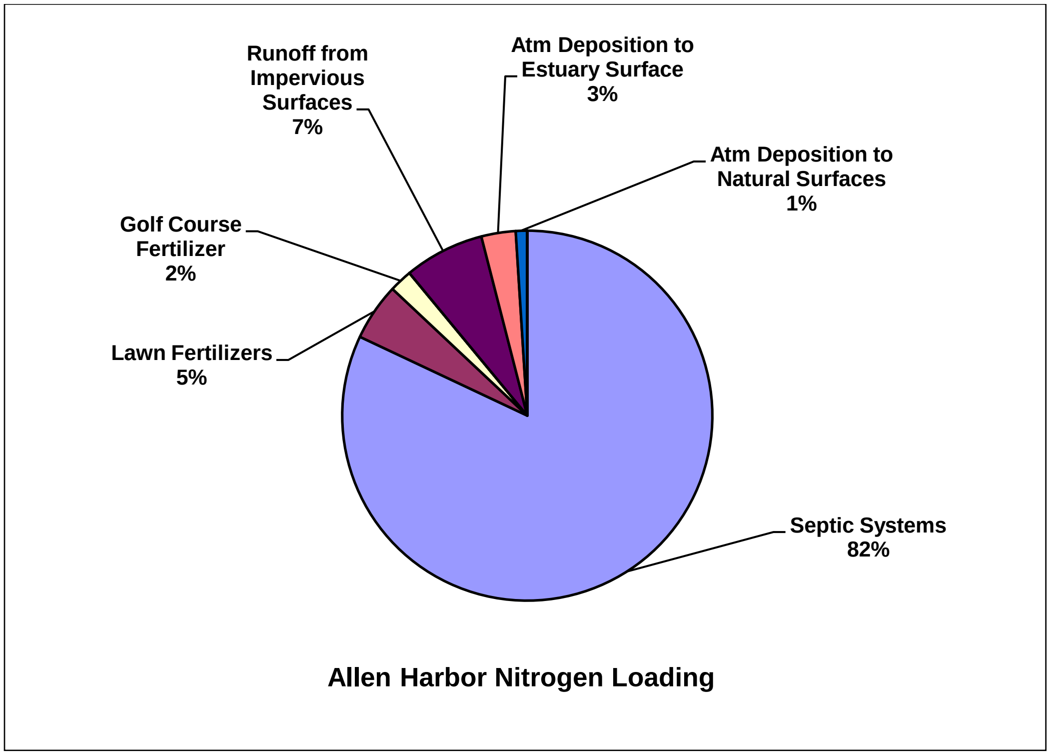


Figure ES-B: Percent Contributions of All Nitrogen Sources to Saquatucket Harbor Embayment System

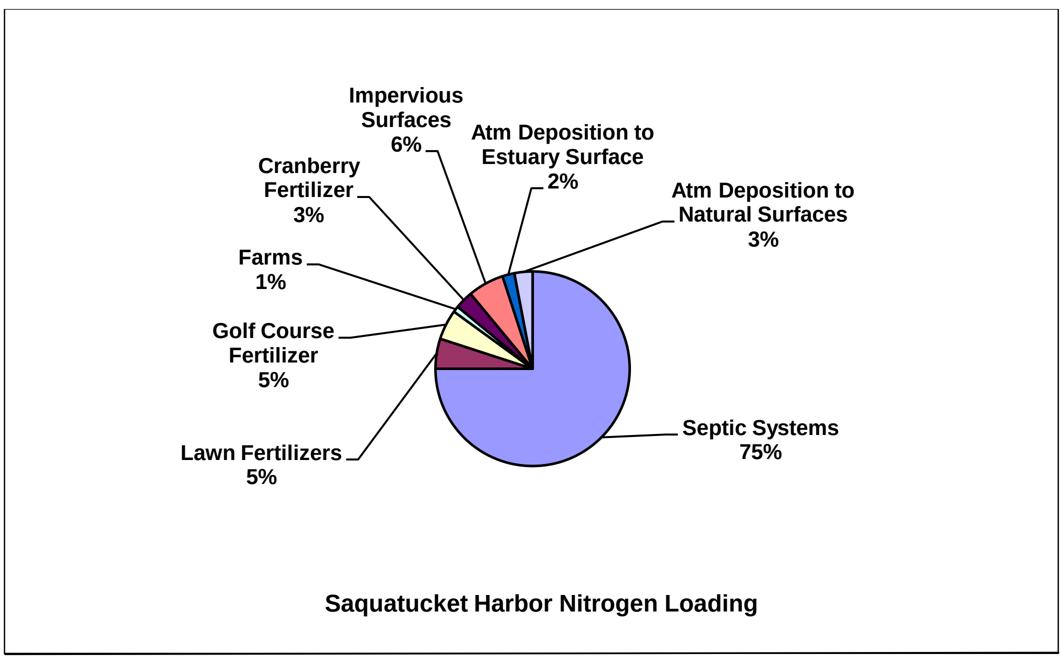
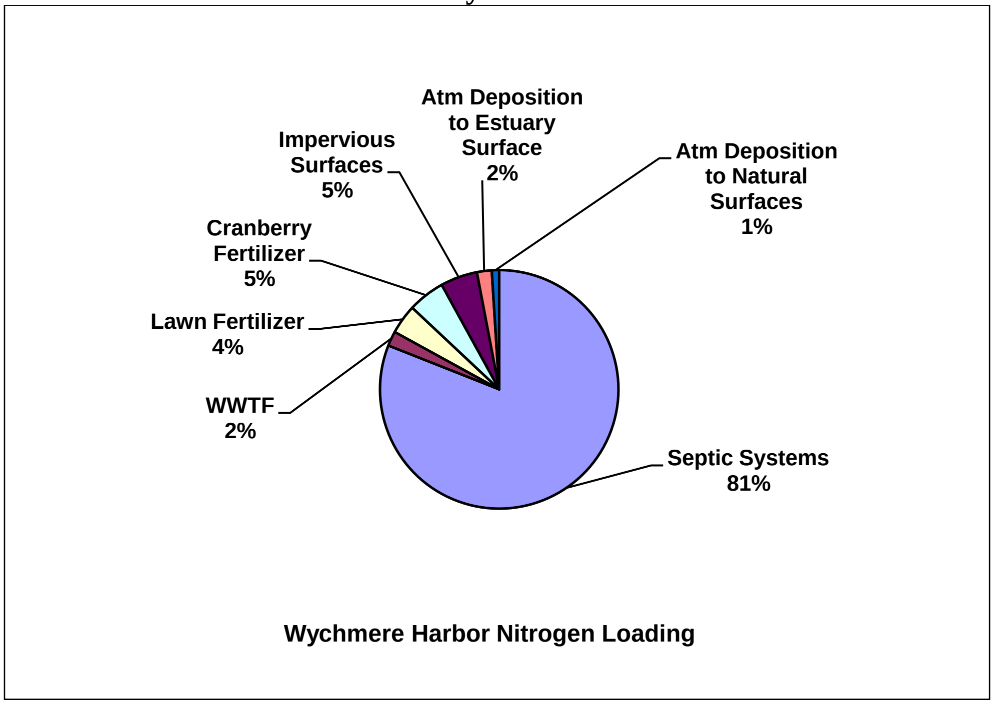


Figure ES-C: Percent Contribution of All Nitrogen Sources to the Wychmere Harbor Embayment System



Target Threshold N Concentrations and Loadings

The N loadings (the quantity of N) to these harbor systems ranged from 1.84 kg/day in Allen Pond Stream to 18.23 kg/day in Saquatucket Harbor, with a total loads for Allen, Wychmere and Saquatucket harbor embayment systems of 19.94, 17.93 and 32.68 kg N/day, (including atmospheric deposition and benthic contributions), respectively. The resultant concentrations of N ranged from 0.673-0.819 mg/L in Allen Harbor, 0.530-0.812 mg/L in Wychmere Harbor and 0.658 mg/L in Saquatucket Harbor (range of average yearly means collected from 8 stations during 2001-2008 as reported in Table VI-1 of the MEP Technical Report, and included in Appendix A of this report).

In order to restore and protect these three harbor embayment systems, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below those that cause the observed environmental impacts. This N concentration will be referred to as the *target threshold N concentration*. The Massachusetts Estuaries Project (MEP) has determined that by achieving a N concentration of 0.50 mg/L at sentinel station HAR-2 in Saquatucket Harbor, sentinel station HAR-3 in Wychmere Harbor and sentinel station HAR-4 in Allen Harbor (see Figure 7), water and habitat quality will be restored in these systems. The mechanism for achieving the target threshold N concentrations is to reduce the N loadings to the watersheds of the harbor embayment systems. Based on the MEP sampling and modeling analyses and their Technical Report, the MEP study has determined that the Total Maximum Daily Loads (TMDL) of N that will meet the target threshold N concentration of 0.50 mg/L range from 1.06 to 11.58 kg/day. This calls for a reduction of 71 – 83 % N loading within the harbor subwatersheds and 41- 43% reduction of N loading within the tributary subwatersheds of each of major surface water sources. This document presents the TMDLs for this water body system and provides guidance to the watershed community of Harwich on possible ways to reduce the N loadings to within the recommended TMDL and protect the waters of these embayment systems.

Implementation

The primary goal of TMDL implementation will be lowering the concentrations of N by greatly reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewering and treatment with N removal technology, advanced treatment of septage, and/or installation of N-reducing on-site systems. Implementing best management practices (BMPs) to reduce N loadings from fertilizers and runoff where possible will also help to lower the total N load to these systems. Potential methods for reducing N loadings from these sources are outlined in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies" that is available on the MassDEP website http://www.mass.gov/eea/agencies/massdep/water/watersheds/coastal-resources-and-estuaries.html. The appropriateness of any of the alternatives will depend on local conditions and will have to be determined on a case-by-case basis using an adaptive management approach. This adaptive management approach will incorporate the priorities and concepts included in the updated area wide management plan established under the Clean Water Act Section 208.

Finally, growth within the Town of Harwich that would exacerbate the problems associated with N loadings should be guided by considerations of water quality-associated impacts.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters that are not meeting water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern) from all contributing sources that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.

2. Assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).

3. Determination of the assimilative loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. Specification of load allocations, based on the loading capacity determination, for non-point sources and point sources that will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. The MassDEP will work with the watershed town of Harwich to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Allen, Wychmere and Saquatucket Harbor embayment systems the pollutant of concern for these TMDLs (based on observations of eutrophication) is the nutrient nitrogen. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton which impairs the healthy ecology of the affected water bodies.

The TMDLs for total N for the Allen, Wychmere and Saquatucket Harbor embayment systems are based primarily on data collected, compiled and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST) Coastal Systems Program and the Town of Harwich Harbor Master Department as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 2001 through 2008. This study period will be referred to as the "present conditions" in the TMDL report since it contains the most recent data available. The accompanying MEP Technical Report can be found at http://www.oceanscience.net/estuaries/reports.htm. The MEP Technical Report presents the results of the analyses of the coastal embayment systems using the MEP Linked Watershed-Embayment N Management Model (Linked Model). The analyses were performed to assist the watershed community with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space and harbor maintenance programs. A critical element of this approach is the assessment of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements and benthic community structure that was conducted on this embayment. These assessments served as the basis for generating a N loading threshold for use as a goal for watershed N management. The TMDLs are based on the site specific N threshold generated for these embayments. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the watershed community of Harwich.

Description of Water Bodies and Priority Ranking

The Allen, Wychmere and Saquatucket Harbor embayment systems are located within the Town of Harwich on the southern shore of Cape Cod, Massachusetts bounded by barrier beaches fronting Nantucket Sound. All of the watersheds of these systems including the estuary portions are entirely located within the Town of Harwich making Harwich the sole municipal steward of these small estuarine systems. (See Figures 1 and 2)

Saquatucket Harbor, Wychmere Harbor and Allen Harbor are all relatively simple estuaries that have each been anthropogenically altered over time to varying degrees. All three have a single tidal outlet through which tidal exchange with Nantucket Sound occurs. With the exception of Allen Harbor that has a small tributary basin near the inlet and a salt marsh at the head, the other two systems are comprised of a single basin.
The open water area of these estuaries is <20 acres in all cases (Wychmere, 16ac; Allen,19ac; Saquatucket, 12ac) placing them among the smaller embayments of southeastern. Massachusetts. Each estuary exchanges tidal waters with Nantucket Sound through inlets that have been "fixed" by jetties, although maintenance dredging is required to maintain maximum tidal flows. All three estuaries are located in the Chatham Outwash Plain, comprised of sands and gravels, chiefly pre-Wisconsin deposits. The result is permeable soils with little runoff and a permeable groundwater aquifer, with aerobic waters. Between each estuarine basin and the sound, a barrier beach has developed from deposited sands and gravels. For the MEP analysis, the open water basin of each system is the principal estuarine basin in the modeling and thresholds analysis, as it is the main receptor of watershed inputs and supports the major estuarine habitats.

The Wychmere, Allen, and Saquatucket Harbors are shallow, ~3m, ~2m and ~3m, respectively and vertically well mixed, with only periodic stratification. Salt marsh is mainly found within Allen and Saquatucket Harbors, but historically the basins supported a much greater emergent marsh area. Saquatucket Harbor was functionally a tidal salt marsh with a central tidal river until 1968 when it was dredged to create the present harbor basin. Allen Harbor still supports a moderately sized and relatively healthy salt marsh in its northern reach, which exchanges waters with the main basin.

Most watershed freshwater and nutrients enter these three estuaries via either groundwater or surface water to varying degrees depending on the system, and all three systems contain marine waters diluted by these freshwater inflows. In the case of Saquatucket Harbor, there are two significant surface water inflows- Cold Stream Brook from the northwest and East Saquatucket Stream from the northeast - that discharge to the headwaters with additional freshwater inflow entering through groundwater discharge directly to the harbor perimeter. In contrast, all the freshwater entering the Wychmere Harbor system is via direct groundwater seepage, as there are no significant surface inflows to this system. Allen Harbor shows an intermediate condition, with a relatively small surface water inflow, an un-named creek passing under Kildee Road (referred to as Allen Pond Stream in the MEP Technical Report and in this TMDL Report), but with most freshwater entering the system directly via groundwater discharge.

These embayment systems constitute an important component of the area’s natural and cultural resources. The nature of enclosed embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline, they are popular regions for boating, recreation, and land development; and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the Allen, Wychmere and Saquatucket Harbors are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Saquatucket Harbor is already listed in the MA 2012 Integrated List of Waters in Category 4a indicating a TMDL for pathogens has been completed (Table 1). Pathogens are listed in Table 1 for completeness. Further discussion of pathogens is beyond the scope of this TMDL.

Table 1. Harwich MEP Study Waterbodies in Category 4a of the MA 2012 Integrated List (MassDEP 2013)

Name	Water Body Segment	Description	Size	Pollutant Listed
Saquatucket Harbor	MA96-23_2012	South of Route 28 to confluence with Nantucket Sound, Harwich	0.02 sq mi	-Pathogens

Complete descriptions of these embayment systems are presented in Chapters I and IV of the MEP Technical Report. A majority of the information presented here is drawn from this report. Chapters VI and VII of the MEP Technical Report provide assessment data that show that the Allen, Wychmere and Saquatucket Harbor systems are impaired because of nutrients, low dissolved oxygen levels, elevated chlorophyll *a* levels, and benthic fauna habitat. Table 2 identifies the segment now in Category 4a of the 2012 Integrated List of Waters by MassDEP with a completed pathogen TMDL and additional segments that were observed to be impaired through the MEP analysis. These segments will be listed as impaired for nutrients in a future MA Integrated List of Waters.

Table 2: Comparison of Impaired Parameters for the Harwich Harbors

Name	DEP Listed Impaired Parameter	SMAST Listed Impaired Parameter
Allen Harbor	--	-Nutrients -DO level -Chlorophyll -Benthic fauna
Wychmere Harbor	--	-Nutrients -DO level -Chlorophyll -Benthic fauna
Saquatucket Harbor	Pathogens	-Nutrients -DO level -Chlorophyll -Benthic fauna

The embayments addressed by this document have been determined to be "high priority" based on three significant factors: (1) the initiative that the Town of Harwich has taken to assess the conditions of the entire embayment system; (2) the commitment made by the town to restore the Allen, Wychmere and Saquatucket Harbors; and (3) the extent of impairment in the Allen, Wychmere and Saquatucket Harbor systems. In both marine and freshwater systems, an excess of nutrients results in degraded water quality, adverse impacts to ecosystems and limits on the use of water resources. Observations are summarized in the Problem Assessment section below and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health of the MEP Technical Report.

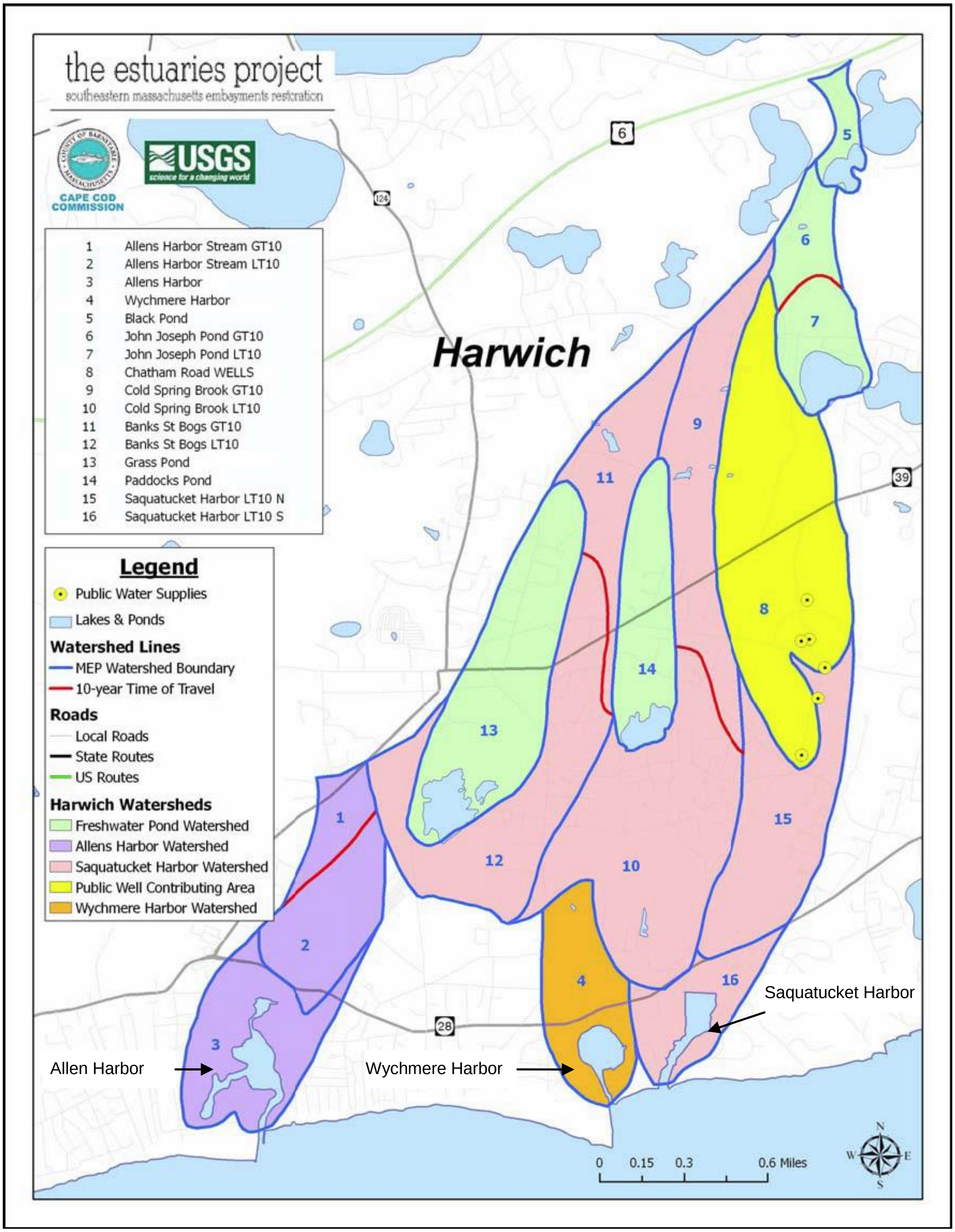


Figure 1: Watershed Delineations for Allen, Saquatucket and Wychmere Harbors.

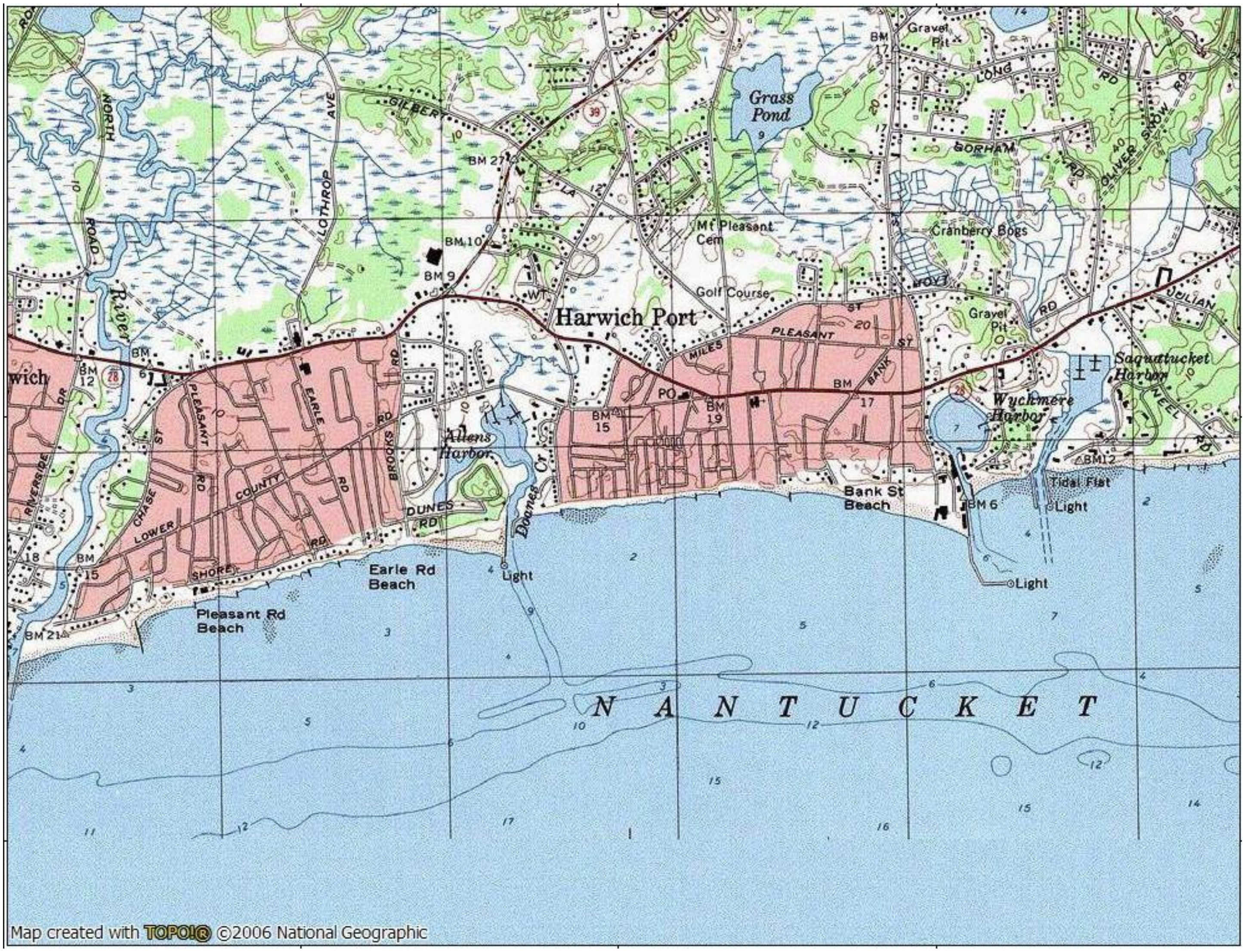


Figure 2: Locus map of Allen Harbor, Wychmere Harbor and Saquatucket Harbor (from United States Geological Survey topographic maps).

Problem Assessment

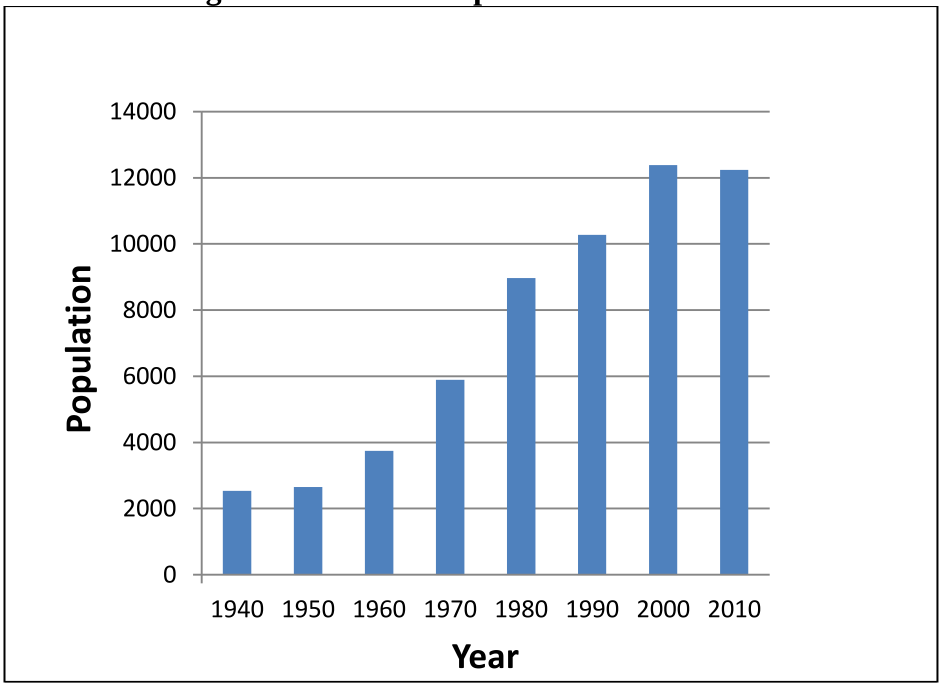
Water quality problems associated with development within the watersheds result primarily from septic systems and from runoff, including fertilizers.

The water quality problems affecting nutrient-enriched embayments generally include periodic decreases of dissolved oxygen, decreased diversity and quantity of benthic animals, and periodic algae blooms. In the most severe cases habitat degradation could lead to periodic fish kills, unpleasant odors and scums and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Harwich, rely on clean, productive and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing and boating, as well as commercial fin fishing and shell fishing. The continued degradation of this coastal embayment, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Figure 3 shows how the year-round population of Harwich has grown from just over 2,000 people in 1940 to over 12,000 people in 2010 (http://www.census.gov/data.html). Increases in N loading to estuaries are directly related to increasing development and population in the watershed. Harwich's population has increased six-fold in the past 70 years. The watersheds of Allen, Wychmere and Saquatucket Harbors have had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. Summer occupancy increases by three-fold in some areas. This increase in population contributes to a decrease in forests and an increase in septic systems, runoff from impervious surfaces and fertilizer use.

Figure 3: Resident Population for Harwich



Habitat and water quality assessments were conducted on these embayment systems based upon water quality monitoring data, changes in eelgrass distribution, time-series water column oxygen measurements and benthic community structure. Given the configuration of each of the harbors and the relatively similar depths of each (generally 2m-3m), these systems almost certainly have similar sensitivities to nitrogen enrichment and organic matter loading. The MEP evaluation of habitat quality supported by each harbor considers the natural structure of each system and its ability to support eelgrass beds and the types of infaunal communities that they support.

At present, Saquatucket Harbor, Wychmere Harbor and Allen Harbor are supporting moderately to significantly impaired habitat quality throughout the open water basins (Table 3). Impairment is indicated by the structure of the benthic communities, periodic oxygen depletion and high levels of chlorophyll *a* and typical concentrations of total nitrogen of 0.65-0.82 mg N /L in the basin waters. There is no evidence that these embayments were ever supportive of eelgrass. For each harbor, all of the health indicators support a consistent assessment as presented below:

Table 3: General Summary of Conditions Related to the Major Indicators of Habitat Impairment Observed in Saquatucket Harbor, Wychmere Harbor, and Allen Harbor Embayment Systems

Health Indicator	**Harwich Harbor Embayment Systems**			
	Allen Harbor		**Saquatucket Harbor**	**Wychmere Harbor**
	Main Basin	**Creek**		
Dissolved Oxygen	MI	SI	MI-SI	MI
Chlorophyll	MI-SI	SI	SI	SI-SD
Macroalgae	-	MI-SI	-	MI
Eelgrass	--	--	--	--
Infaunal Animals	MI-SI	SI	MI-SI	MI-SI
Overall	**MI**	**SI**	**MI-SI**	**MI-SI**

H - Healthy Habitat Conditions*
MI – Moderately Impaired*
SI – Significantly Impaired- considerably and appreciably changed from normal conditions*
SD – Severe Degraded – critically or harshly changed from normal conditions*
* - These terms are more fully described in MEP report "Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators" December 22, 2003 http://www.mass.gov/eea/agencies/massdep/water/watersheds/the-massachusetts-estuaries-project-mep.html
\- drift algae sparse or absent
-- no evidence this basin is supportive of eelgrass

Pollutant of Concern, Sources, and Controllability

In the coastal embayments of the Town of Harwich, as in most marine and coastal waters, the limiting nutrient is N. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions including the severe impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

The embayments addressed in this TMDL report have had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) including cooperation and assistance from the University of Massachusetts –SMAST, Town of Harwich Natural Resources Department, the US Geological Survey, Applied Coastal Research and Engineering, Inc and the Cape Cod Commission. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report.

Figures 4 - 6 illustrate the sources of N to Allen, Saquatucket and Wychmere Harbor Embayment Systems. Most of the N affecting these systems originates from on-site subsurface wastewater disposal systems (septic systems). The level of "controllability" of each source, however, varies widely:

Atmospheric deposition– Although helpful, local controls are not adequate – it is only through region- and nation-wide air pollution control initiatives that significant reductions are feasible, however the N from these sources might be subjected to enhanced natural attenuation as it moves towards the estuary.

Fertilizer –Fertilizer and related N loadings can be reduced through best management practices (BMPs), bylaws and public education.

Agricultural – related N loadings can be controlled through the application of agricultural BMPs.

Impervious surfaces and storm water runoff sources of N can be controlled by applying BMPs, bylaws and stormwater infrastructure improvements and public education.

Septic system sources of N can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing N-reducing on-site wastewater treatment systems.

WWTF – the Town of Harwich does not have a centralized waste water treatment facility (WWTF) however The Snow Inn maintains its own treatment facility. The leach fields for this facility are located within the watershed for Wychmere Harbor near the channel that connects this harbor to Nantucket Sound.

Cost/benefit analyses will have to be conducted on all possible N loading reduction methodologies in order to select the optimal control strategies, priorities and schedules.

Figure 4: Percent Contribution of All Nitrogen Sources to the Allen Harbor Embayment System

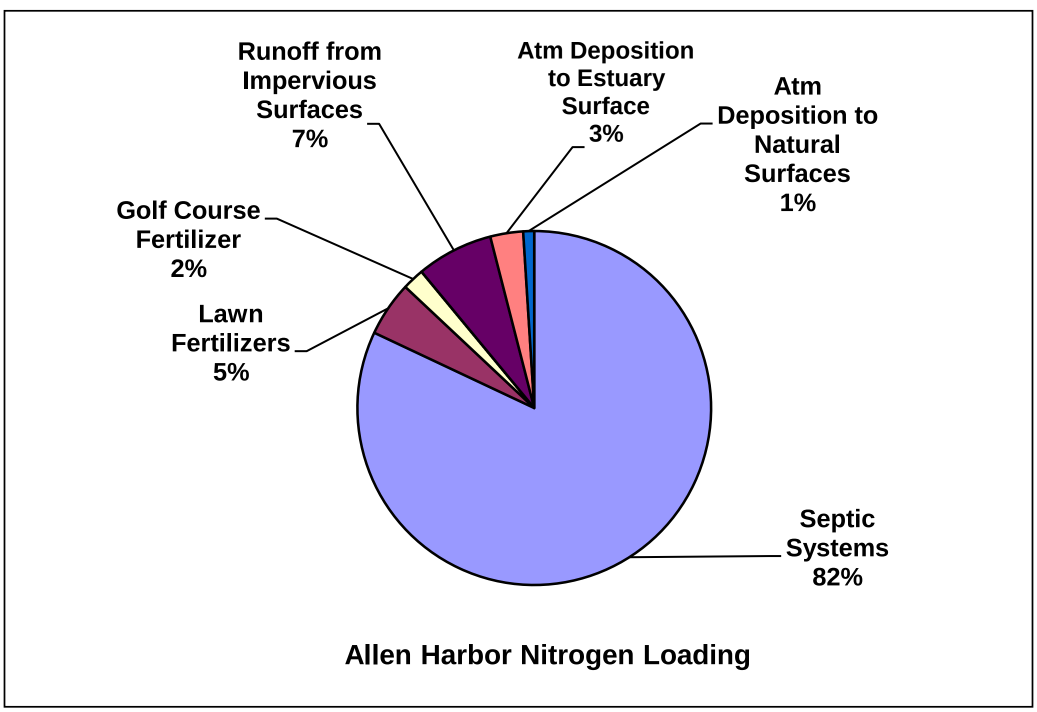


Figure 5: Percent Contribution of All Nitrogen Sources to the Saquatucket Harbor Embayment System

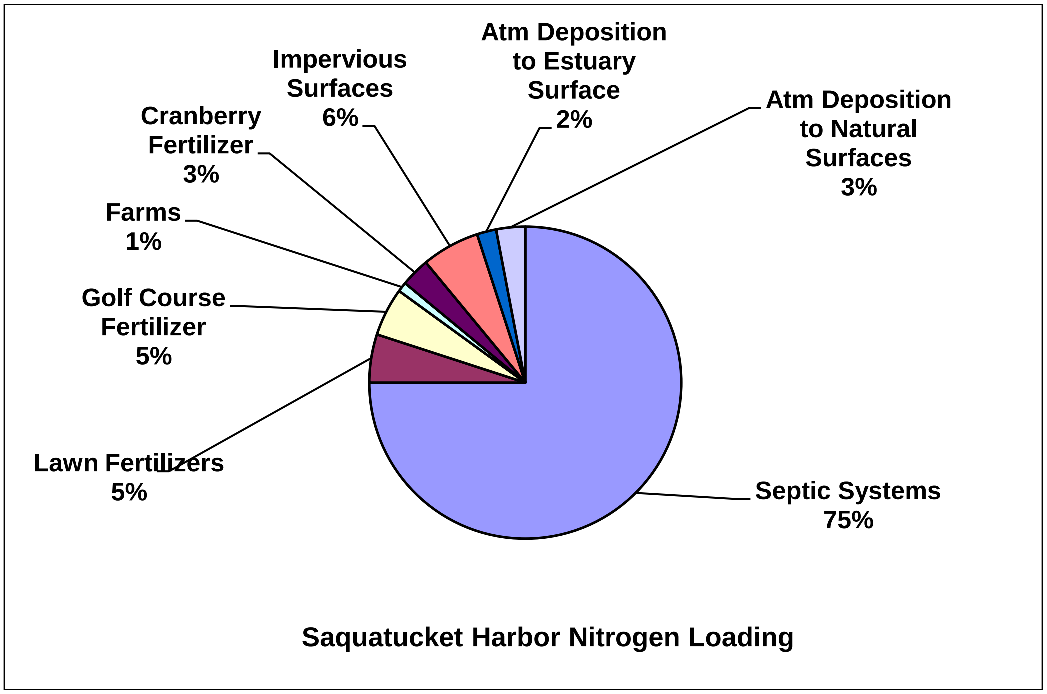
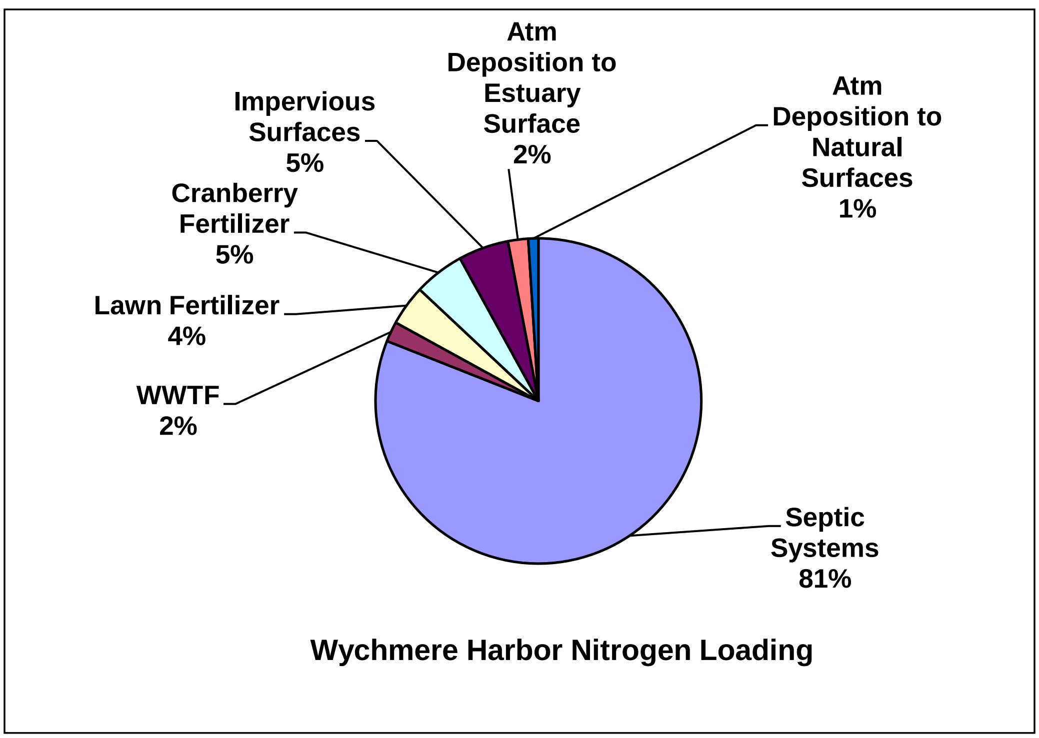


Figure 6: Percent Contribution of All Nitrogen Sources to the Wychmere Harbor Embayment System



Description of the Applicable Water Quality Standards

The water quality classification of the saltwater portions of Allen, Wychmere, Saquatucket Harbor embayment systems are SA, and the freshwater portions of the systems are classified as B. Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states: "Aesthetics – All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances; produce objectionable odor, color, taste, or turbidity; or produce undesirable or nuisance species of aquatic life."

314 CMR 4.05(5)(b) states: "Bottom Pollutants or Alterations. All surface waters shall be free from pollutants in concentrations or combinations or from alterations that adversely affect the physical or chemical nature of the bottom, interfere with the propagation of fish or shellfish, or adversely affect populations of non-mobile or sessile benthic organisms."

314 CMR 4.05(5)(c) states: "Nutrients. Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established…"

314 CMR 4.05(b) 1:

Class SA:
Dissolved Oxygen -
a. Shall not be less than 6.0 mg/L unless background conditions are lower;
b. Natural seasonal and daily variations above this level shall be maintained.

Class B:
Dissolved Oxygen -
a. Shall not be less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries;
b. Where natural background conditions are lower, DO shall not be less than natural background conditions. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.

Thus, the assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The Guidance Manual notes that lakes, reservoirs, streams and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters tend to have unique characteristics and development of individual water body criteria is typically required.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each embayment. Physical (Chapter V), chemical and biological (Chapters IV, VII, and VIII) data were collected and evaluated. The primary water quality objective was represented by conditions that:

1) Restore the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish;
2) Prevent algal blooms;
3) Restore and preserve benthic communities;

4) Maintain dissolved oxygen concentrations that are protective of the estuarine communities.
The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

- Requires site specific measurements within the watershed and each sub-embayment;
- Uses realistic "best-estimates" of N loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- Spatially distributes the watershed N loading to the embayment;
- Accounts for N attenuation during transport to the embayment;
- Includes a 2D or 3D embayment circulation model depending on embayment structure;
- Accounts for basin structure, tidal variations, and dispersion within the embayment;
- Includes N regenerated within the embayment;
- Is validated by both independent hydrodynamic, N concentration, and ecological data;
- Is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model has been applied previously to watershed N management in over 50 embayments thus far throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment becomes a N management-planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. Also, since the Linked Model uses a holistic approach that incorporates the entire watershed, embayment and tidal source waters, it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. It should be noted that this approach includes high-order, watershed and sub-watershed scale modeling necessary to develop critical nitrogen targets for each major sub-embayment. The models, data and assumptions used in this process are specifically intended for the purposes stated in the MEP Technical Report, upon which this TMDL is based. As such, the Linked Model process does not contain the type of data or level and scale of analysis necessary to predict the fate and transport of nitrogen through groundwater from specific sources. In addition, any determinations related to direct and immediate hydrologic connection to surface waters are beyond the scope of the MEP's Linked Model process.

The Linked Model provides a quantitative approach for determining an embayment's (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation and recycling and variations in tidal hydrodynamics (Figure I-4 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

- Monitoring - multi-year embayment nutrient sampling

- Hydrodynamics -
    - Embayment bathymetry (depth contours throughout the embayment)
    - Site-specific tidal record (timing and height of tides)
    - Water velocity records (in complex systems only)

- Hydrodynamic model

• Watershed Nitrogen Loading
  - Watershed delineation
  - Stream flow (Q) and N load
  - Land-use analysis (GIS)
  - Watershed N model

• Embayment TMDL - Synthesis
  - Linked Watershed-Embayment Nitrogen Model
  - Salinity surveys (for linked model validation)
  - Rate of N recycling within embayment
  - Dissolved oxygen record
  - Macrophyte survey
  - Infaunal survey (in complex systems)

Application of the Linked Watershed-Embayment Model

The approach developed by the MEP for applying the linked model to specific embayments, for the purpose of developing target N loading rates, includes:

1) Selecting one or two sub-embayments within the embayment system located close to the inland-most reach or reaches which typically has the poorest water quality within the system. These are called "sentinel" stations;

2) Using site-specific information and a minimum of three years of sub-embayment-specific data to select target threshold N concentrations for each sub-embayment. This is done by refining the draft target threshold N concentrations that were developed as the initial step of the MEP process. The target threshold N concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;

3) Running the calibrated water quality model using different watershed N loading rates to determine the loading rate that will achieve the target threshold N concentration at the sentinel station. Differences between the modeled N load required to achieve the target threshold N concentration and the present watershed N load represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses and the modeling activities described above resulted in four major outputs that were critical to the development of the TMDL. Two outputs are related to **N concentration:**

- the present N concentrations in the sub-embayments
- site-specific target threshold N concentrations.

And, two outputs are related to **N loadings:**

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target N concentrations.

In summary, meeting the water quality standards by reducing the N concentration (and thus the N load) at the sentinel station(s) will result in the water quality goals being met throughout the entire system.

A brief overview of each of the outputs follows.

Nitrogen concentrations in the embayment

a) Observed "present" conditions:

Table 4 presents the average concentrations of N measured in theses embayments from eight years of data collection by the Harwich Water Quality Monitoring Program (2001 through 2008). The overall means and standard deviations of the averages are presented in Appendix A (taken from Table VI-1 of the MEP Technical Report). Water quality sampling stations are shown in Figure 7 below.

b) Modeled site-specific target threshold N concentrations:

The target threshold N level for an embayment represents the average water column concentration of N that will support the habitat quality or dissolved oxygen conditions being sought. The water column N level is ultimately controlled by the integration of the watershed N load, the N concentration in the inflowing tidal waters (boundary condition) and dilution due to ground or surface water flows. The water column N concentration is also modified by the extent of sediment regeneration, by direct atmospheric deposition, and phytoplankton uptake.

A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific target threshold N concentrations by using the specific physical, chemical and biological characteristics of each harbor embayment system.

As listed in Table 4 below, the site-specific target threshold N concentration is 0.50 mg/L. The findings of the analytical and modeling investigations to determine this target threshold nitrogen concentration for the embayment system are discussed below.

Table 4: Present Nitrogen Concentrations and Sentinel Station Threshold Nitrogen Target Concentrations for the Harwich Harbors Embayment Systems

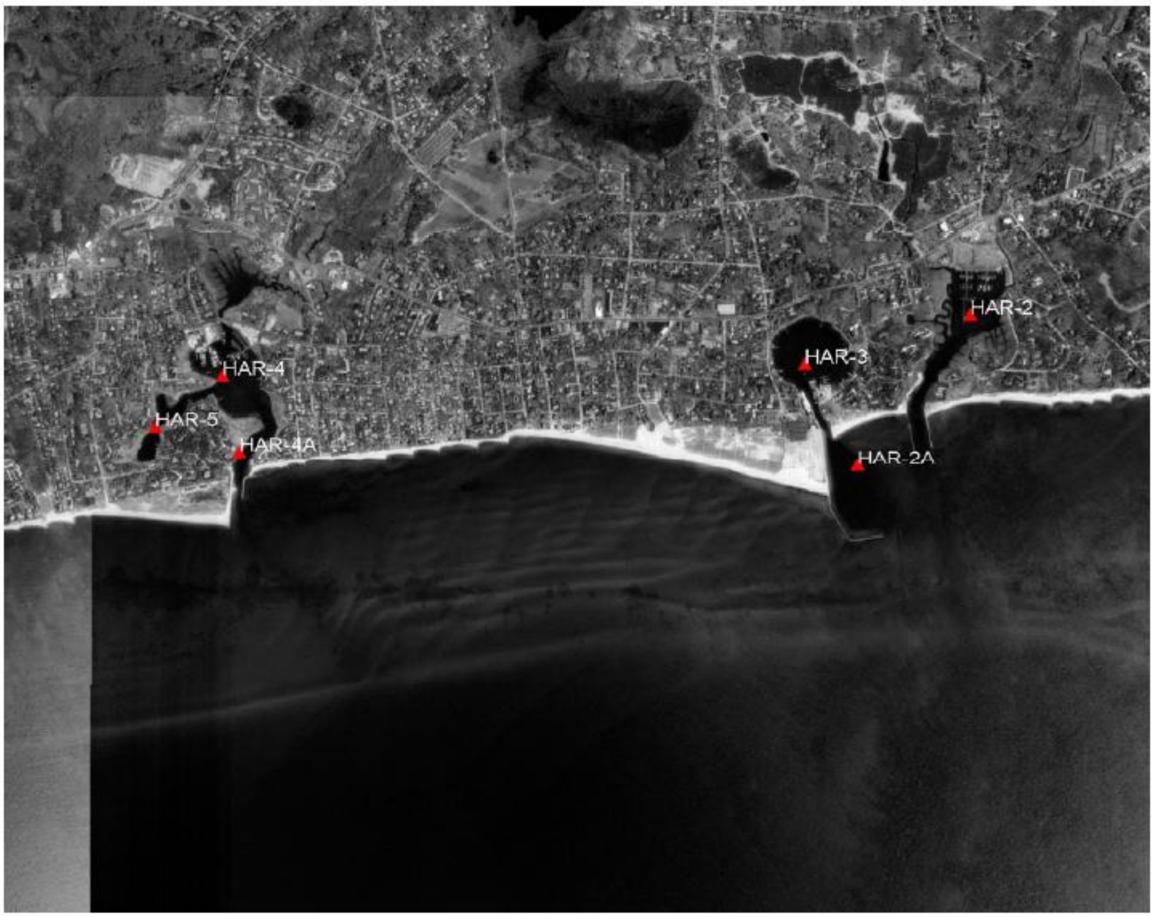
Harbor System/Sentinel Station	Observed Nitrogen Concentration [1] (mg/L)	Target Threshold Nitrogen Concentration (mg/L)
Allen Harbor/HAR-4	0.747	0.50
Wychemere Harbor/HAR-3	0.812	0.50
Saquatucket Harbor/HAR-2	0.658	0.50

[1] Average total N concentrations from present loading based on an average of the annual N means from 2001 - 2008.

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout an embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the MEP study modeled nitrogen loads until the targeted nitrogen concentration was achieved. Target threshold N concentrations in this study were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as diverse benthic animal communities and dissolved oxygen levels that would support Class SA waters since eelgrass habitat could not be documented to exist, either historically or presently, within Saquatucket, Wychmere or Allen Harbors.

The sentinel stations for each of the three estuaries are located within the main basin at the long-term water quality monitoring stations: Saquatucket Harbor (HAR-2), Wychmere (HAR-3) and Allen Harbor (HAR-4) (Figure 7). However, given the potential for tidal restriction to Allen Creek, it is necessary to include a secondary "check" station specific to that basin (HAR-5). The secondary check station in Allen Creek is to provide a check on the acceptability of conditions within the tributary basin at the point that the threshold level is attained at the sentinel station and to control for potential tidal restriction between this tributary basin and the main basin. The goal is to achieve the nitrogen target at the sentinel location and restore benthic animal habitat throughout each of the three harbors.

Figure 7: Water Quality Sampling Stations in Allen, Wychmere and Saquatucket Harbors
(The sentinel stations are HAR-4, HAR-3, HAR-2, respectively.)



According to the MEP technical report the observed benthic habitat quality is completely consistent with the observed levels of oxygen depletion, chlorophyll a and macroalgal accumulations (only found in Allen Creek). These indicators are supported by the total nitrogen concentrations found in the MEP study, where average TN levels in all the harbors ranged from 0.65 – 0.82 mg/L N, with the highest levels observed in Allen Creek. The MEP studies have generally found benthic habitat quality to be highest in open water basins with TN levels generally between 0.50-0.55 mg/L N. For example, high quality benthic habitats within the Bumps River and Lower Centerville River were found at TN levels <0.46 mg/L N. Similarly, the moderate impairment of infaunal habitat in the inner basins of Hyannis Inner Harbor were found at only slightly higher tidally averaged total nitrogen levels of 0.518-0.574 mg/L N. These data are consistent with a variety of studies by the MEP Technical Team in other enclosed basins along Nantucket Sound (e.g. Perch Pond, Bournes Pond, Popponesset

Bay) where levels <0.5 mg/L N were found to be supportive of healthy infaunal habitat and in deeper terminal basins (e.g. Eel Pond in Bourne) where healthy infaunal habitat had a slightly lower threshold level, 0.45 mg/L N. Further analysis of the Centerville River Estuary indicates moderate impairment at tidally averaged N levels >0.5 mg/L N (0.526 mg/L N) in Scudder Bay and at 0.543 mg/L N in the mid reach of the Centerville River. Moderate impairment was also observed at the same N levels (0.535-0.600 mg/L N) within the Wareham River, with high quality infaunal animal habitat at N levels of 0.444-0.463 mg/L N. Based upon these observations, it was concluded that an upper limit of 0.50 mg/L tidally averaged N would support healthy infaunal habitat in each of the basins of the three harbors.

The findings of the analytical and modeling investigations for these embayment systems are discussed and explained below.

<u>Nitrogen loadings to the embayment</u>

a) Present Loading rates:

In the Allen, Wychmere and Saquatucket Harbor embayment systems overall the highest N loading from controllable sources is from on-site wastewater treatment systems. The MEP Technical Report (Figure IV-5) calculates that septic systems account for 86%, 83% and 79% of the controllable N load to Allen, Wychmere and Saquatucket Harbors, respectively. Other minor sources include lawn and golf course fertilizers, cranberry bogs, farm animals, the Snow Inn WWTP facility and runoff from impervious surfaces. Nitrogen rich sediments in this system are also a major contribution. However, reducing the N load to the estuary will also reduce N in the sediments since the magnitude of the benthic contribution is related to the watershed load.

A subwatershed breakdown of N loading, by source, is presented in Table 5. The data on which Table 5 is based can be found in Table ES-1 of the MEP Technical Report.

As previously indicated, the present N loadings to these embayment systems must be reduced in order to restore the impaired conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required that will achieve the target threshold N concentrations.

b) Nitrogen loads necessary for meeting the site-specific target threshold N concentrations:

Table 6 lists the present watershed N loadings from the Allen, Wychmere and Saquatucket Harbor systems and the percent watershed load reductions necessary to achieve the target threshold N concentration at the sentinel stations (from Table ES-2 of the MEP Technical Report).

These modeling results provide one scenario of achieving the threshold level for the sentinel sites within these estuary systems. It is very important to note that load reductions can be produced through a variety of strategies or combination of strategies such as the reduction of any or all sources of N, increasing the natural attenuation of N within the freshwater systems, and/or modifying the tidal flushing through inlet reconfiguration (where appropriate). This scenario establishes the general degree and spatial pattern of reduction that will be required for restoration of the N impaired portions of these harbor systems. The Town of Harwich is encouraged to evaluate all potential options and take any reasonable actions to reduce the controllable N sources.

Table 5: Present Nitrogen Loadings to Allen, Wychmere and Saquatucket Harbor Embayment Systems

Sub-watershed	Present Non-Wastewater Watershed Load[1] (kg N/day)	Present Septic System Load (kg N/day)	Present Watershed Load[4] (kg N/day)	Present Atmospheric Deposition[2] (kg N/day)	Present Benthic Flux[3] (kg N/day)	Total nitrogen load from all sources (kg N/day)[5]
Allen Harbor	0.550	4.214	4.764	0.227	13.109	18.1
Wychmere Harbor	0.592	3.208	3.866[6]	0.195	13.865	17.926
Saqutucket Harbor	0.250	2.545	2.795	0.151	15.285	18.231
Allen Pond Stream	0.412	1.426	1.838	--	--	1.838
Cold Spring Brook	2.726	7.775	10.501	--	--	10.501
East Saquatucket Stream	1.022	2.926	3.948	--	--	3.948

[1] Includes fertilizers, runoff, and atmospheric deposition to lakes and natural surfaces
[2] Atmospheric deposition to the estuarine surface only
[3] Nitrogen loading from sediments
[4] Includes fertilizer, runoff and wastewater inputs
[5] Composed of fertilizer, runoff, wastewater, atmospheric deposition and benthic nitrogen input
[6] Includes an additional 0.066 kg/day from the Snow Inn WWTP.

Table 6: Present Watershed Nitrogen Loading Rates, Calculated Loading Rates that are Necessary to Achieve Target Threshold Nitrogen Concentrations, and the Percent Reductions of the Existing Loads Necessary to Achieve the Target Threshold Loadings.

Harbor System	Present Total Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] (kg N/day)	Watershed Load Reductions Needed to Achieve Target Loads	
			kg N/day	% change
Allen Harbor	4.764	1.392	3.372	-70.78%
Wychmere Harbor	3.866	0.66	3.206	-82.93%
Saquatucket Harbor	2.795	0.756	2.039	-72.95%
Allen Pond Stream	1.838	1.055	0.783	-42.60%
Cold Spring Brook	10.501	6.225	4.276	-40.72%
East Saquatucket Stream	3.948	2.296	1.652	-41.84%

[1] Composed of fertilizer, runoff, atmospheric deposition to lakes and natural surfaces, WWTF and septic system loadings.
[2] Target threshold watershed load is the N load from the watershed (including natural background) needed to meet the target threshold N concentration of 0.50 mg/L for each of the embayments.

Total Maximum Daily Loads

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no "numerical" water quality standards for N, the TMDLs for Allen, Wychmere and Saquatucket Harbor systems are aimed at determining the loads that would correspond to specific N concentrations determined to be protective of the water quality and ecosystems.

The development of a TMDL requires detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time) for each waterbody system. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll *a* and benthic infauna.

The TMDL can be generally defined by the equation:

TMDL = BG + WLAs + LAs + MOS

Where

TMDL = loading capacity of receiving water
BG = natural background
WLAs = portion allotted to point sources
LAs = portion allotted to (cultural) non-point sources
MOS = margin of safety

Background Loading

Natural background N loading is included in the loading estimates presented here, but is neither quantified nor presented separately. It is a component of the target watershed threshold. . Background loading was calculated on the assumption that the entire watershed is forested with no anthropogenic sources of N. It is accounted for in this TMDL but not defined as a separate component. Readers are referred to Table ES-1 of the MEP Technical Report for estimated loading due to natural conditions.

Waste Load Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. There are no permitted surface water discharges to the Allen, Wychmere and Saquatucket Harbor systems with the exception of stormwater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of stormwater be included in the waste load component of the TMDL. EPA and MassDEP authorized most of the Town of Harwich for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. The watersheds of all three harbors lie entirely within the designated MS4 areas of Harwich.

For purposes of the Allen, Wychmere and Saquatucket TMDLs, MassDEP also considered the nitrogen load reductions from regulated MS4 sources necessary to meet the target nitrogen concentrations. In estimating the nitrogen loadings from regulated stormwater sources, MassDEP considered that most stormwater runoff in the MS4 communities is not discharged directly into surface waters, but, rather, percolates into the ground. The geology on Cape Cod and the Islands consists primarily of glacial outwash sands and gravels, and water moves rapidly through this type of soil profile. A systematic survey of stormwater conveyances in Harwich had not been conducted prior to or during the MEP technical study of these embayments. Nevertheless, most catch basins on Cape Cod and the Islands are known to MassDEP to have been designed as leaching catch basins in light of the permeable overburden. MassDEP, therefore, recognized that most stormwater that enters a catch basin in the regulated area will percolate into the local groundwater table rather than directly discharge to a surface waterbody. As described in the Methodology Section (above), the Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source. However, MassDEP also considered that some stormwater collected in regulated area is discharged directly to surface waters through outfalls. In the absence of specific data or other information to accurately quantify stormwater discharged directly to surface waters, MassDEP assumed that all impervious surfaces within 200 feet of the shoreline, as calculated from MassGIS data layers, would discharge directly to surface waters, whether or not it in fact did so. MassDEP selected this approach because it considered it unlikely that any stormwater collected farther than 200 feet from the shoreline would be directly discharged into surface waters. Although the 200 foot approach provided a gross estimate, MassDEP considered it a reasonable and conservative approach given the lack of pertinent data and information about MS4 systems on Cape Cod. For Allen, Wychmere and Saquatucket Harbors this calculated stormwater WLA based on the 200 foot buffer is 0.13 kg/day N (), 0.11 kg/day N and 0.03 kg/day N respectively. These WLAs amount to 1.7 % of the total N load to Allen Harbor, 2.7% of the total N load into Wychmere Harbor and 0.1% into Saquatucket Harbor (see Appendix C for details). This conservative load is a negligible amount of the total nitrogen load to these embayments when compared to other sources.

Load Allocations

Load allocations identify the portion of loading capacity allocated to existing and future nonpoint sources. In the case of the Allen, Wychmere and Saquatucket Harbor systems the nonpoint source loadings are primarily from septic systems (see Figure 8). Additional N sources include fertilizers from lawns, golf courses and cranberry bogs, farm animals, Snow Inn WWTP (groundwater discharge), natural background, stormwater runoff (from non-impervious areas), and atmospheric deposition.

Stormwater that is subject to the EPA Phase II Program is considered a part of the wasteload allocation, rather than the load allocation . As discussed above and presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source, thus combining the assessments of wastewater and storm water for the purpose of developing control strategies. As the Phase II Program is implemented in Harwich, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through implementation of Best Management Practices (BMPs).

The sediment loading rates incorporated into the TMDL are lower than the existing benthic input listed in Table 5 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments and therefore, over time, reductions in loadings from the sediments will occur. Benthic N flux is a function of N loading and particulate organic N (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads and are calculated by multiplying the present N flux by the ratio of projected PON to present PON using the following formulae:

Projected N flux = (present N flux) (PON projected / PON present)

When: $PON\ projected = (R_{load})\ (D_{PON}) + PON_{present\ offshore}$

When $R_{load} = (projected\ N\ load) / (Present\ N\ load)$

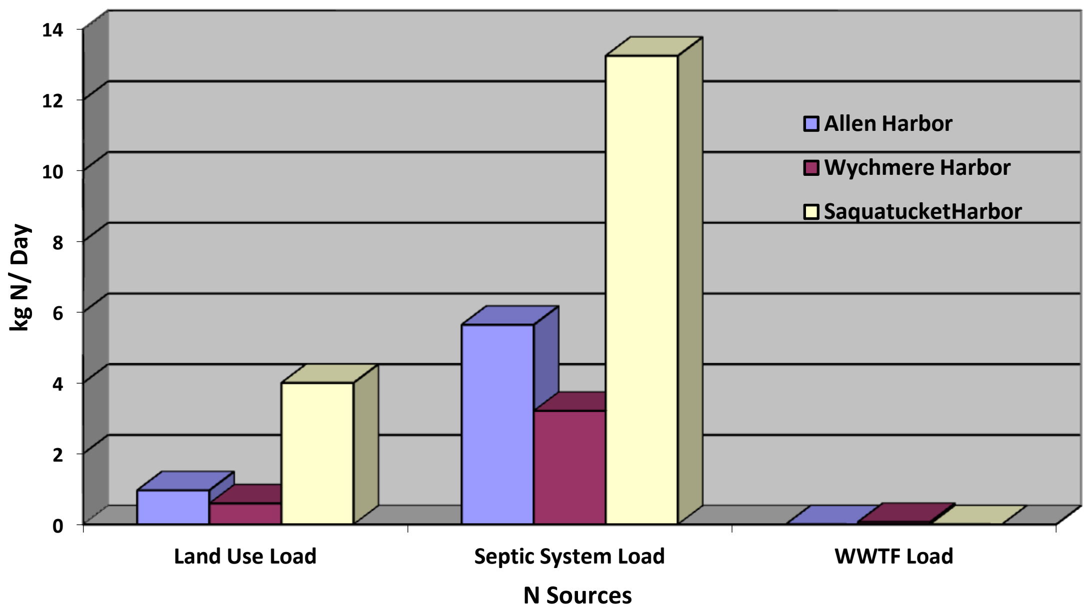
And D_{PON} is the PON concentration above background determined by:
$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$

The benthic flux modeled for the Allen, Wychmere and Saquatucket Harbor systems is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Nantucket Sound (boundary condition). The benthic flux input to each sub-embayment was reduced (toward zero) based on the reduction of N in the watershed load.

The loadings from atmospheric sources incorporated into the TMDL however, are the same rates presently occurring because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes and land use (which includes stormwater runoff and fertilizers). Figure 8 illustrates that septic systems are by far the most significant portion of the controllable N load. Septic systems contribute 22.1 kg/day of N to the combined harbor systems while fertilizers and runoff combined contribute just 5.6 kg/day (represented as land use load in Figure 8). The WWTF load is from the Snow Inn which discharges to groundwater within the Wychmere Harbor watershed (from Table ES-1 in the MEP Technical Report).

Figure 8: Allen, Wychmere and Saquatucket Controllable N Loads



Margin of Safety

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)20©, 40C.G.R. para 130.7©(1)]. The MOS must be designed to ensure that any uncertainties in the data or calculations used to link pollutant sources to water quality impairment modeling will be accounted for in the TMDL and ensure protection of the beneficial uses. The EPA’s 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. An explicit MOS quantifies an allocation amount separate from other Load and Wasteload Allocations. An explicit MOS can incorporate reserve capacity for future unknowns, such as population growth or effects of climate change on water quality. An implicit MOS is not specifically quantified but consists of statements of the conservative assumptions used in the analysis. The MOS for the Allen, Wychmere and Saquatucket Harbors TMDLs is implicit. MassDEP used conservative assumptions to develop numeric model applications that account for the MOS. These assumptions are described below, and they account for all sources of uncertainty, including the potential impacts of changes in climate.

While the general vulnerabilities of coastal areas to climate change can be identified, specific impacts and effects of changing estuarine conditions are not well known at this time (http://www.mass.gov/eea/waste-mgnt-recycling/air-quality/green-house-gas-and-climate-change/climate-change-adaptation/climate-change-adaptation-report.html). Because the science is not yet available, MassDEP is unable to analyze climate change impacts on streamflow, precipitation, and nutrient loading with any degree of certainty for TMDL development. In light of these uncertainties and informational gaps, MassDEP has opted to address all sources of uncertainty through an implicit MOS. MassDEP does not believe that an explicit MOS approach is appropriate under the circumstances or will provide a more protective or accurate MOS than the implicit MOS approach, as the available data simply does not lend itself to characterizing and estimating loadings to derive numeric allocations within confidence limits. Although the implicit MOS approach does not expressly set aside a specific portion of the load to account for potential impacts of climate change, MassDEP has no basis to conclude that the conservative assumptions that were used to develop the numeric model applications are insufficient to account for the lack of knowledge regarding climate change.

Conservative Assumptions used in the Margin of Safety:

1. Use of conservative data in the linked model

The watershed N model provides conservative estimates of N loads to the embayment. Nitrogen transfer through direct groundwater discharge to estuarine waters is based upon studies indicating negligible aquifer attenuation and dilution, i.e. 100% of load enters embayment. This is a conservative estimate of loading because studies have also shown that in some areas less than 100% of the load enters the estuary. In this context, “direct groundwater discharge” refers to the portion of fresh water that enters an estuary as groundwater seepage into the estuary itself, as opposed to the portion of fresh water that enters as surface water inflow from streams, which receive much of their water from groundwater flow. Nitrogen from the upper watershed regions, which travel through ponds or wetlands, almost always enter the embayment via stream flow, are directly measured (over 12-16 months) to determine attenuation. In these cases the land-use model has shown a slightly higher predicted N load than the measured discharges in the streams/rivers that have been assessed to date. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads because the actual measured N in streams was lower than the modeled concentrations.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been >95%. Field measurement of instantaneous discharge was performed using acoustic doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an $R2>0.95$, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high degree of confidence in the output; therefore, less of a margin of safety is required.

In the case of N attenuation by freshwater ponds, attenuation was derived from measured N concentrations, pond delineations and pond bathymetry for just one of the ponds. This attenuation rate was determined to be 74%. All other ponds lacked sufficient data to calculate an attenuation factor so a more conservation value of 50% was applied as more protective and defensible. Nitrogen attenuation in freshwater ponds has generally been determined by the MEP analysis to be at least 50%, so the watershed model assigns a conservative attenuation of 50% to all nitrogen from freshwater pond watersheds unless there is sufficient information to develop a pond-specific attenuation rate to incorporate into the loading analysis.

Similarly, the water column N validation dataset was also conservative. The model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement two times higher than the next highest data point in the series raises the average 0.05 mg N/L, this would allow for a higher "acceptable" load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

In addition, the predicted reductions in benthic regeneration of N are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of PON, due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification, denitrification and sediment oxidation will increase.

Benthic regeneration of N is dependent upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column versus being denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions (1) PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and (2) Presently enhanced production will decrease in proportion to the reduction in the sum of watershed N inputs and direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading and direct atmospheric deposition could be reduced to zero (an impossibility of course). This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result, future N regeneration rates are overestimated which adds to the margin of safety.

2. <u>Conservative sentinel station/target threshold nitrogen concentration</u>

Conservatism was used in the selection of the sentinel stations and target threshold N concentrations. The sites were chosen that had stable eelgrass or benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentration. Meeting the target threshold N concentrations at the sentinel stations will result in reductions of N concentrations in the rest of the systems.

3. <u>Conservative approach</u>

The linked model accounted for all stormwater loadings and groundwater loadings in one aggregate allocation as a non point source and this aggregate load is accounted for in the load allocation. The method of calculating the WLA in the TMDL for regulated stormwater was conservative as it did not disaggregate this negligible load from the modeled stormwater LA, hence this approach further enhances the margin of safety.

The target loads were based on tidally averaged N concentrations on the outgoing tide, which is the worst case condition because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides and therefore this approach is conservative.

In addition to the margin of safety within the context of setting the N threshold levels as described above, a programmatic margin of safety also derives from continued monitoring of these embayments to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

Seasonal Variation

Since the TMDLs for the waterbody segments are based on the most critical time period, i.e. the summer growing season, the TMDLs are protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the embayment are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual manipulation since the majority of the N is from non-point sources. Thus, the annual loads make sense since it is difficult to control non-point sources of N on a seasonal basis and N sources can take considerable time to migrate to impacted waters.

TMDL Values for Allen, Wychmere and Saquatucket Harbor Embayment Systems

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of the embayment were calculated by considering all sources of N grouped by natural background, point sources and non-point sources. A more meaningful way of presenting the loadings data from an implementation perspective is presented in Table 7.

In this table the N loadings from the atmosphere are listed separately from the target watershed threshold loads which are composed of natural background N along with locally controllable N from the on-site subsurface wastewater disposal systems, storm water runoff and fertilizer sources. In the case of Allen, Wychmere and Saquatucket Harbor embayment systems the TMDLs were calculated by projecting reductions in locally controllable septic systems. Once again the goals of these TMDLs are to achieve the identified target threshold N concentration at the identified sentinel stations. The target loads identified in this table represents one alternative-loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

Table 7: The Total Maximum Daily Loads (TMDL) for Allen, Wychmere and Saquatucket Harbor Embayment Systems, Represented as the Sum of the Calculated Target Threshold Loads, Atmospheric Deposition and Sediment Load

Harbor System	Target Threshold Watershed Load[1] (kg N/day)	Atmospheric Deposition (kg N/day)	Nitrogen Load from Sediments[2] (kg N/day)	TMDL[3] (kg N/day)
Allen Harbor	1.392	0.227	8.216	9.835
Wychmere Harbor	0.66	0.195	6.03	6.885
Saquatucket Harbor	0.756	0.151	10.67	11.557
Allen Pond Stream	1.055	--	--	1.055
Cold Spring Brook	6.225	--	--	6.225
East Saquatucket Stream	2.296	--	--	2.296

[1] Target threshold watershed load (including natural background) is the load from the watershed needed to meet the embayment target threshold nitrogen concentration identified in Table 4.
[2] Projected sediment N loadings obtained by reducing the present loading rates (Table 5) proportional to proposed watershed load reductions and factoring in the existing and projected future concentrations of PON from Table ES-2 of the MEP Technical Report.
[3] Sum of target threshold watershed load, sediment load and atmospheric deposition load.

Implementation

The critical element of this TMDL process is achieving the sentinel station specific target threshold N concentration presented in Table 4 above that is necessary for the restoration and protection of water quality and diverse benthic communities within the Allen, Wychmere and Saquatucket Harbor embayment systems. In order to achieve the target threshold N concentration, N loading rates must be reduced throughout the harbor embayment systems.

Septic Systems:
Table 8 presents a load reducing scenario based solely on reducing the septic loads from the Allen, Wychmere and Saquatucket Harbor watersheds. However, as previously noted, there are a variety of loading reduction scenarios that could achieve the target threshold N concentrations. Local officials are encouraged to explore other loading reduction scenarios through additional modeling as part of their Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated however, that any alternative implementation strategies will be protective of the entire embayment system. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the town in achieving target N loads that will result in the desired target threshold N concentration.

Table 8: Summary of the Present On-Site Subsurface Wastewater Disposal System Loads, and the Loading Reductions Necessary to Achieve the TMDL by Reducing On-Site Subsurface Wastewater Disposal System Loads Only

Harbor System/Subwatershed	Present Septic System Load (kg N/day)	Threshold Septic System Load (kg N/day)	Threshold Septic System Load % Change
Allen Harbor[1]	4.214	0.841	-80%
Wychmere Harbor[1]	3.208	0.000	-100%
Saquatucket Harbor[1]	2.545	0.507	-80.1%
Allen Pond Stream	1.426	0.642	-54.9%
Cold Spring Brook	7.775	3.499	-55%
East Saquatucket Stream	2.926	1.274	-56.5%

[1]Total estuarine reach which receives septic N inputs through direct groundwater discharge and from surface water (stream) inflows

(Note: Taken from Table VIII-2 of the MEP Technical Report. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.)

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the MassDEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results. This adaptive management approach will incorporate the priorities and concepts included in the updated area wide management plan established under the Clean Water Act Section 208.

Because the vast majority of controllable N load is from septic systems for private residences the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations and denitrifying systems for all private residences.

If a community chooses to implement TMDL measures without a CWMP it must demonstrate that these measures will achieve the target threshold N concentration. (Note: Communities that choose to proceed without a CWMP will not be eligible for State Revolving Fund 0% loans.)

Stormwater:
The NPDES permits which EPA has issued in Massachusetts to implement the Phase II Stormwater program do not establish numeric effluent limitations for stormwater discharges, rather, they establish narrative requirements, including best management practices, to meet the following six minimum control measures and to meet State Water Quality Standards.
1. public education and outreach particularly on the proper disposal of pet waste,
2. public participation/involvement,
3. illicit discharge detection and elimination,
4. construction site runoff control,
5. post construction runoff control, and
6. pollution prevention/good housekeeping.

As part of their applications for Phase II permit coverage, communities must identify the best management practices they will use to comply with each of these six minimum control measures and the measurable goals they have set for each measure. Therefore, compliance with the requirements of the Phase II stormwater permit in the Town of Harwich will contribute to the goal of reducing the nitrogen load as prescribed in this TMDL for Allen, Wychmere and Saquatucket Harbor watersheds.

In their 2014 annual Phase II MS4 Stormwater reports to EPA, Harwich reports that 100% of the mapping of the stormdrain system and outfalls in the town has been completed and field verification is ongoing. The annual reports indicate that they continue to update stormwater drainage systems to Phase II standards. In addition, the Town conducts an ongoing public outreach campaign that includes website, posters, handouts, mailers and flyers with information on various pollution prevention activities (e.g., hazardous waste collections) and regulations.

Other activities being conducted by Harwich as reported in their most recent (2014) NPDES Phase II MS4 Annual Report include: membership in the Pleasant Bay Resource Management Alliance (The Alliance has over 100 volunteers who collect water samples throughout the Bay from June through September); hosting COASTSWEEP which organizes volunteer beach cleaning events in Harwich; working with Americorps of Cape Cod to clean streams related to herring runs in Harwich; collecting waste oil from boats at Saquatucket Harbor for proper disposal.

Climate Change:
MassDEP recognizes that long-term (25+ years) climate change impacts to southeastern Massachusetts, including the area of this TMDL, are possible based on known science. Massachusetts Executive Office of Energy and Environmental Affairs 2011Climate Change Adaptation Report: http://www.mass.gov/eea/waste-mgnt-recycling/air-quality/green-house-gas-and-climate-change/climate-change-adaptation/climate-change-adaptation-report.html predicts that by 2100 the sea level could be from 1 to 6 feet higher than the current position and precipitation rates in the Northeast could increase by as much as 20 percent. However, the details of how climate change will affect sea level rise, precipitation, streamflow, sediment and nutrient loading in specific locations are generally unknown. The ongoing debate is not about whether climate change will occur, but the rate at and the extent to which it will occur and the adjustments needed to address its impacts. EPA's 2012 Climate Change Strategy
http://water.epa.gov/scitech/climatechange/upload/epa_2012_climate_water_strategy_full_report_final.pdf
states: "Despite increasing understanding of climate change, there still remain questions about the scope and timing of climate change impacts, especially at the local scale where most water-related decisions are made." For estuarine TMDLs in southeastern Massachusetts, MassDEP recognizes that this is particularly true, where

water quality management decisions and implementation actions are generally made and conducted at the municipal level on a sub-watershed scale.

EPA's Climate Change Strategy identifies the types of research needed to support the goals and strategic actions to respond to climate change. EPA acknowledges that data are missing or not available for making water resource management decisions under changing climate conditions. In addition, EPA recognizes the limitation of current modeling in predicting the pace and magnitude of localized climate change impacts and recommends further exploration of the use of tools, such as atmospheric, precipitation and climate change models, to help states evaluate pollutant load impacts under a range of projected climatic shifts.

In 2013, EPA released a study entitled, "Watershed modeling to assess the sensitivity of streamflow, nutrient, and sediment loads to potential climate change and urban development in 20 U.S. watersheds." (National Center for Environmental Assessment, Washington D.C.; EPA/600/R-12/058F). The closest watershed to southeastern Massachusetts that was examined in this study is a New England coastal basin located between Southern Maine and Central Coastal Massachusetts. These watersheds do not encompass any of the watersheds in the Massachusetts Estuary Project (MEP) region, and it has vastly different watershed characteristics, including soils, geography, hydrology and land use – key components used in a modeling analysis. The initial "first order" conclusion of this study is that, in many locations, future conditions, including water quality, are likely to be different from past experience. However, most significantly, this study did not demonstrate that changes to TMDLs (the water quality restoration targets) would be necessary for the region. EPA's 2012 Climate Change Strategy also acknowledges that the Northeast, including New England, needs to develop standardized regional assumptions regarding future climate change impacts. EPA's 2013 modeling study does not provide the scientific methods and robust datasets needed to predict specific long-term climate change impacts in the MEP region to inform TMDL development.

MassDEP believes that impacts of climate change should be addressed through TMDL implementation with an adaptive management approach in mind. Adjustments can be made as environmental conditions, pollutant sources, or other factors change over time. Massachusetts Coastal Zone Management (CZM) has developed a StormSmart Coasts Program (2008) to help coastal communities address impacts and effects of erosion, storm surge and flooding which are increasing due to climate change. The program, www.mass.gov/czm/stormsmart offers technical information, planning strategies, legal and regulatory tools to communities to adapt to climate change impacts.

As more information and tools become available, there may be opportunities to make adjustments in TMDLs in the future to address predictable climate change impacts. When the science can support assumptions about the effects of climate change on the nitrogen loadings to Allen, Wychmere and Saquatucket Harbors the TMDL can be reopened, if warranted.

In summary, the Town of Harwich is urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater BMPs in addition to reductions in on-site subsurface wastewater disposal system loadings.

Based on land-use and the fact that the watersheds of these systems are located completely within the Town of Harwich it follows that nitrogen management necessary for the restoration of the Allen, Wychmere and Saquatucket Harbor embayment systems may be formulated and implemented entirely through the Town of Harwich's actions.
MassDEP's "MEP Embayment Restoration Guidance for Implementation Strategies":
http://www.mass.gov/eea/agencies/massdep/water/watersheds/coastal-resources-and-estuaries.html provides N

loading reduction strategies that are available to Harwich and that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
    - On-Site Treatment and Disposal Systems
    - Cluster Systems with Enhanced Treatment
    - Community Treatment Plants
    - Municipal Treatment Plants and Sewers
- Tidal Flushing
    - Channel Dredging
    - Inlet Alteration
    - Culvert Design and Improvements
- Stormwater Control and Treatment *
    - Source Control and Pollution Prevention
    - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
    - Smart Growth
    - Open Space Acquisition
    - Zoning and Related Tools
- Nutrient Trading

*Harwich is one of the 237 communities in Massachusetts covered by the 2003 Phase II storm water program permit requirements.

Monitoring Plan

MassDEP is of the opinion that there are two forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL. MassDEP's position is that implementation will be conducted through an iterative process where adjustments may be needed in the future. The two forms of monitoring include 1) tracking implementation progress as approved in the Harwich CWMP plans and 2) monitoring water quality and habitat conditions in the estuaries, including but not limited to, the sentinel stations identified in the MEP Technical Report.

The CWMP will evaluate various options to achieve the goals set out in the TMDL report and the MEP Technical Report. It will also make a final recommendation based on existing or additional modeling runs, set out required activities, and identify a schedule to achieve the most cost effective solution that will result in compliance with the TMDL. Once approved by the Department tracking progress on the agreed upon plan will, in effect, also be tracking progress towards water quality improvements in conformance with the TMDL.

Relative to water quality, MassDEP believes that an ambient monitoring program much reduced from the data collection activities needed to properly assess conditions and to populate the model, will be important to determine actual compliance with water quality standards. Although the TMDL values are not fixed, the target threshold N concentrations at the sentinel stations are fixed. Through discussions amongst the MEP participants it is generally agreed that existing monitoring programs which were designed to thoroughly assess conditions and populate water quality models can be substantially reduced for compliance monitoring purposes. Although more specific details need to be developed on a case-by-case basis MassDEP believes that about half the current effort (using the same data collection procedures) would be sufficient to monitor compliance over time and to observe trends in water quality changes. In addition, the benthic habitat and communities would require periodic monitoring on a frequency of about every 3-5 years. Finally, in addition to the above, existing monitoring conducted by MassDEP for eelgrass should continue into the future to observe any changes that may occur to eelgrass populations as a result of restoration efforts.

The MEP will continue working with the watershed communities to develop and refine monitoring plans that remain consistent with the goals of the TMDL. It must be recognized however that development and implementation of a monitoring plan will take some time, but it is more important at this point to focus efforts on reducing existing watershed loads to achieve water quality goals.

Reasonable Assurances

MassDEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL through its many permitting programs including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Harwich has demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The town expects to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act, Title 5 regulations for on-site subsurface wastewater disposal systems and other local regulations (such as the Town of Rehoboth's stable regulations). Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MassDEP and EPA. Other potential funds and assistance are available through the Massachusetts Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

As the town implements these TMDLs the loading values (kg/day of N) will be used by MassDEP for guidance for permitting activities and should be used by the community as a management tool.

Public Participation

Public meetings to present the results of and answer questions on this TMDL were held on XXXXin the XXXX meeting room. XXXXX (MassDEP) summarized the Mass Estuaries Project and described the Draft Nitrogen TMDL Report findings. Public comments received at the public meetings and comments received in writing within a 30-day comment period following the public meeting were considered by the Department. This final version of the TMDL report includes both a summary of the public comments together with the Department's response to the comments and scanned images of the attendance sheets from the meetings (Appendix xx. MEP representatives at the public meetings included XXXXXXX.

Appendix A

Table A-1: Summary of the Nitrogen Concentrations for Allen, Wychmere and Saquatucket Harbor Embayment Systems.

Measured data and modeled Total Nitrogen concentrations for the Allen, Wychmere and Saquatucket Harbor estuary systems used in the model calibration plots of Figure VI-3. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Data are provided courtesy of the Costal Systems Program at SMAST. (From Table VI-1of the MEP Technical Report.)

Sub-Embayment	**Saquatucket Harbor**	**Wychmere Harbor (Outer)**	**Wychmere Harbor**	**Allen Harbor Marina**	**Allen Harbor Hulse Pt.**	**Allen Harbor Creek**
Monitoring Station	**HAR-2**	**HAR-2A**	**HAR-3**	**HAR-4**	**HAR-4A**	**HAR-5**
2001 mean	0.669	--	0.658	1.135	--	1.187
2002 mean	0.546	0.470	0.712	0.689	0.516	0.679
2003 mean	0.643	0.506	0.887	0.481	0.534	0.525
2004 mean	0.584	0.533	0.847	0.484	0.538	0.576
2005 mean	0.587	0.505	0.639	0.488	0.473	0.482
2006 mean	0.720	0.588	0.875	1.130	1.144	1.141
2007 mean	0.698	0.551	0.956	0.697	0.939	1.415
2008 mean	0.819	0.542	0.892	0.902	0.794	0.997
mean	0.658	0.530	0.812	0.747	0.673	0.819
s.d. all data	0.169	0.128	0.254	0.323	0.252	0.400
N	76	34	77	43	34	38
model min	0.627	0.409	0.763	0.592	0.335	0.794
model max	0.680	0.558	0.846	0.749	0.675	0.825
model average	0.652	0.453	0.813	0.679	0.451	0.808

Appendix B

Table B-1: Allen, Wychmere and Saquatucket Harbor Embayment Systems 3 Total Nitrogen TMDLs and 3 Pollution Prevention TMDLs

Embayment/Sub-embayment	Segment ID/Description	Description	TMDL (kg N/day)
Allen Harbor	--/South of Rt 28, Harwich to confluence with Nantucket Sound, Harwich. West of Wychmere Harbor.	Determined to be impaired for nutrients during the development of this TMDL.	9.835
Allen Pond Stream	--/Unnamed stream that flows into Allen Harbor from the northeast under Kildee Road.	Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	1.055
Wychmere Harbor	--/South of Rt 28, Harwich to confluence with Nantucket Sound, Harwich. West of Saquatucket Harbor.	Determined to be impaired for nutrients during the development of this TMDL.	6.885
Saquatucket Harbor	MA96-23-2012/ South of Rt 28, Harwich to confluence with Nantucket Sound, Harwich	Determined to be impaired for nutrients during the development of this TMDL.	11.557
Cold Spring Brook	--/Stream flows from the north into the northwest side of Saquatucket Harbor.	Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	6.225
East Saquatucket Stream	--/ Stream flows from the north into the northeast side of Saquatucket Harbor.	Not impaired for total nitrogen, but TMDL needed since embayments are linked. (Pollution Prevention TMDL)	2.296

Appendix C

Table C-1: The Allen, Wychmere and Saquatucket Harbor Embayment Systems estimated waste load allocation (WLA) from runoff of all impervious areas within 200 feet of its waterbodies.

Estuary System Name	Watershed Impervious Area in 200 ft Buffer of Embayment Waterbody (acres)[1]	Total Watershed Impervious Area (acres)[2]	Watershed Impervious Area in 200 ft buffer as % of Total Watershed Impervious Area	MEP Total Unattenuated Watershed Impervious Load (kg N/day)[3]	MEP Total Unattenuated Watershed Load (kg N/day)[4]	Watershed Impervious buffer (200 ft) WLA (kg N/day)[5]	Watershed buffer area WLA as % of MEP Total Unattenuated Watershed Load[6]
Allen Harbor	9.79	40.77	24%	0.54	7.61	0.13	1.7%
Wychmere Harbor	8.67	16.1%	53.9%	0.21	4.06	0.11	2.71%
Saquatucket Harbor	4.71	318.15	1.5%	1.86	28.99	0.03	0.10%

[1]The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated by MassGIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the waste load allocation (WLA) it was assumed that all impervious surfaces within 200 feet of the shoreline discharge directly to the waterbody.
[2]Total impervious surface for the watershed was obtained from SMAST N load data files.
[3]From Table IV-3 of the MEP Technical Report.
[4]This includes the unattenuated nitrogen loads from wastewater from septic systems, fertilizer, runoff from both natural and impervious surfaces, and atmospheric deposition to freshwater waterbodies. This does not include direct atmospheric deposition to the estuary surface.
[5]The impervious subwatershed 200 ft buffer area (acres) divided by total watershed impervious area (acres) then multiplied by total impervious subwatershed load (kg N/day).
[6]The impervious subwatershed buffer area WLA (kg N/day) divided by the total subwatershed load (kg N/day) then multiplied by 100.